

A Comparison of Cognitive Processes
and Components of Neurological Maturation
in 3-and-11-Year-Old Children

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ABSTRACT

The relationship between the child's cognitive development and neurological maturation has been of theoretical interest for many years. Due to difficulties such as the lack of sophisticated techniques for measuring neurological changes and a paucity of normative data, few studies exist that have attempted to correlate the two factors. Recent theory on intellectual development has proposed that neurological maturation may be a factor in the increase of short-term memory storage space. Improved technology has allowed reliable recordings of neurological maturation. In an attempt to correlate cognitive development and neurological maturation, this study tested 3- and 11-year old children. Fine motor and gross motor short-term memory tests were used to index cognitive development. Somatosensory evoked potentials elicited by median nerve stimulation were used to measure the time required for the sensation to pass along the nerve to specific points on the somatosensory pathway. Times were recorded for N14, N20, and P22 interpeak latencies. Maturation of the central nervous system (brain and spinal cord) and the peripheral nervous system (outside the brain and spinal cord) was indicated by the recorded times. Significant developmental differences occurred between 3- and 11-year-olds in memory levels, peripheral conduction velocity and central conduction times. Linear regression analyses showed that as age increased, memory levels increased and central conduction times decreased. Between the 11-year-old groups, there were no significant differences in central or peripheral nervous system maturation between subjects who achieved a 12 plus score on the digit span test of the WISC-R and those who scored 7 or lower on the same test. Levels achieved on the experimental gross and fine motor short-term memory tests differed significantly within the 11-year-old group.

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CHAPTER ONE

Introduction

In recent years, a great deal of data has emerged concerning the education and intellectual development of children. Advances in medicine and technology have also increased at a rapid rate allowing us an improved insight into the factors affecting neurological maturation. However, few attempts have been made to integrate new information on neurological development with children's education and intellectual development.

Neurological data is usually collected from human subjects with anomalies in clinical situations or on animal subjects. As a result, there is very little normative data on human subjects. Psychologists have pursued the assessment of the child's intellectual abilities using psychoeducational tests which measure performance but have not measured the brain activity associated with these tests. Educational theorists have alluded to neurophysiological changes that occur with learning but have not ventured beyond speculation. Educators employ alternative teaching strategies in response to current theories. Each of the

above disciplines has evolved in relative isolation to the others leaving us with a fragmented view of the child. In order to reach a more comprehensive view, this study concerned itself with both the intellectual development of the child and the corresponding neurological changes that occur with maturation.

From Theory to Practice

Many educational theorists have alluded to the importance of neurological development without specifically making the connection with corresponding cognitive processes that are measured with psychoeducational tests. Baldwin, Piaget, Pascual-Leone, and Bruner have all recognized neurological maturation as a factor in the child's intellectual development but were limited in exploration of this area by the lack of sophisticated technical equipment. As a result, information abounds on cognitive development as measured by performance tests but little is known about the corresponding neurological changes.

In the medical field, technical equipment has become more sophisticated and it is now possible to accurately measure some of the neurophysiological changes that occur with development. One of the non-invasive methods of measuring changes in the

nervous system is a somatosensory evoked potential (appendix 1) which measures time varying changes in potential generated by the brain in response to electrical stimulation of a peripheral nerve. Changes in evoked potentials parallel physiological maturation of the central nervous system (Holmes, 1986). Different components of somatosensory evoked potentials represent nerve activity at different points along the somatosensory pathway. This allows the measurement of conduction times or permits conduction velocities to be calculated which in turn is one of the indicators of neurological maturation. Conduction speeds can be recorded for both the peripheral nervous system and the central nervous system. Therefore technology is now available that enables us to correlate cognitive processes and neurological maturation.

Case (1985) has developed a model of intellectual growth which attempts to explain increased capacity for short-term memory storage in terms of neurological maturation. He suggests that the increase in short-term storage space (STSS) with age is due to increased efficiency of the operating space (appendix 1). He further speculates that the increase in operational efficiency is due not only to practice but also maturational changes in the nervous system. Case believes that myelin may be responsible for this maturational change.

Working memory has long been used as a psychoeducational technique with relevance to learning the skills involved in reading. Short-term storage space or working memory is one of the cognitive processes for which there are many psychoeducational tests. These tests show that the number of items that can be retained in memory increases with age (Case, 1985; Dempster, 1981; Howard and Polich, 1985). Case (1985) argues that this may be a good index of cognitive development. If maturation of the nervous system can be measured by conduction speeds and cognitive development can be measured by memory span then the correlation between cognitive processing and neurological maturation can be studied.

Some attempts have been made to correlate cognitive functions and neurological development (Obrzut, Morris, Wilson, Lord, and Caraveo, 1987; Howard and Polich 1985). A study by Howard and Polich (1985) correlated memory span and latency from a late-appearing (P300) component of an evoked potential in children 5 to 15 years of age. Obrzut et al. (1987) reviewed studies that indicated significant differences in evoked responses between learning disabled children and their age-matched peers. These studies measured brain stem evoked responses to an auditory stimulus and in most cases found significant differences in evoked responses between learning disabled children and their age-matched peers.

At the present time there are no known studies which correlate cognitive development with conduction times along the somatosensory pathway. Normative data for conduction speeds exists in general age groups but the researcher was unable to uncover normative data for any specific age group except through one source of correspondence (Cracco, June 16, 1986). Therefore, the research problem is one of determining the relationship between cognitive development as measured by short-term storage space and neurological development as measured by conduction speeds. Comparisons were made between 3-year-old children, 11-year-old children with good memory scores, and 11-year-old children with poor memory scores. It was expected that conduction speeds and STSS would increase with age and STSS and conduction speeds would show a correlation. The assumption in this study is that cognitive processes are controlled by neurological maturation. A limiting factor in this study was the difficulty of finding children with a scaled score of seven or less on the digit span test due to policies of confidentiality at the school board level. Access to testing facilities for evoked potentials including equipment and expertise could be another limitation. However, for this study the researcher was fortunate to have the co-operation of Dr. McLean and the Evoked Potential Laboratory at University of Alberta hospital.

Recent models of intellectual development have incorporated former theories to produce a more comprehensive view of the child that includes cognitive development and neurological maturation. Sophisticated medical technology has allowed the measurement of neural growth through the use of evoked potentials. Cognitive development can be assessed in several ways. One of these is the number of items that can be retained in memory or short-term storage space (STSS). Using somatosensory evoked potentials, conduction speeds in the nervous system can now be correlated with cognitive processes in 3- and 11-year-old children.

CHAPTER TWO

Review of Literature

Cognitive Development and Physiological Ties

It has long been known that maturation and learning are parts of a symbiotic relationship involved in the process of intellectual development. Historically, emphasis has shifted between theories that view the child's learning processes as proceeding from either external or internal experiences. Most theories embrace both to some extent but usually emphasize either the socio-cultural (external) aspect or the physiological-maturational side (internal).

As early as 1894, James Baldwin, an American psychologist, believed that children's intellectual functioning moved through a series of higher stages that were determined by the maturation of the cortex. He viewed the child as an evolving biological organism. By observing his own children, he noted that successful reactions to a stimulus were repeated and eventually became automated. Unsuccessful responses to a stimulus were

discarded and another response was applied to the new situation and the habit formation began again. Baldwin attributed this process of accommodation to attention span which in turn was due to cortical co-ordination. Cortical co-ordination included the development of brain cells, development of connecting brain fibres and myelination of interconnecting nerve fibres. He also observed universal stages of development in which the retention of schemes in memory increased with age. Baldwin's term "attention span" referred to the number of ideas to which a child can pay attention at any one time. He assumed this "attention span" to be limited by neurological factors and noted that the span changed with age. The rate of this change set a limit on the child's rate of intellectual development.

Piaget (cited in Case, 1985) pursued that part of Baldwin's work related to the universal stages and the relationship of these stages to the child's knowledge of the world. Piaget collected empirical data on this intellectual behaviour of humans at different points in time. This collection of data revealed seven stages of development in which concepts appear to be acquired at the same age across a wide variety of domains. Each stage recapitulates the previous one but at a higher level of complexity. Piaget felt this predictable rate of learning to be governed by physiological maturation (Joyce & Weil, 1980). However, Piaget assigned little importance to the maturational

factor after the first few years and instead emphasized physical and social experience and the child's concern in attaining equilibrium.

Pascual-Leone, (cited in Case, 1985) a student of Piaget, revised the theory of child development to include the growth of M power (attention or mental power) similar to Baldwin's "attention span". He found that M space increased with age reflecting a higher order of learning. This higher order of learning was a result of the schemes which the child used to represent the world and not the results of direct experience with the world. He suggested that instruction should be geared to M power of the age group.

Bruner's (1964) theory of cognitive development viewed the child as the inheritor of cultural tools but recognized that development takes place from inside out as well as outside in. The child responds to the active efforts of the culture according to his internal biological disposition. Along with other information processing theorists of the 1960's, one of the contributions to understanding the child's intellectual development was "the realization that data on children's basic sensory and memorial capacities and data on their logical understanding should be unified" (Case, 1985, p.50).

Case, (1985) has distilled the foregoing theories by maintaining

their essence, synthesizing them, and adding postulates of his own to produce a comprehensive model of intellectual development which is rooted in empirical studies. Case's model of intellectual development consists of three major sections: a model of children's basic intellectual structures; a model of stages; a model of stage transition. In the stage transition model, Case has suggested that myelination of the central nervous system may be the maturational factor accounting for the growth in short-term storage space.

When Baldwin used the term "attention span" he meant the number of ideas to which a child can pay attention at any one time. Pascual-Leone adopted the term M power and Case (1985) has referred to it as "executive processing space." He also makes a further distinction between the mental activity involved in executing an ongoing operation (operational efficiency) and the mental activity of retrieving the product of such an operation (short-term storage space) (Case, 1985).

According to Case (1985), total processing space in intellectual development consists of operating space (devoted to the activation of new schemes) plus short term storage space (maintenance or retrieval of recently activated schemes.) In a series of four experiments, Case, Kurland and Goldberg (1982)

required adults to remember nonsense words and invented numbers. Under these conditions, the adult memory span was reduced to that of a 6-year-old child. These studies provided strong evidence to support Case's premise that increased STSS is a result of increase in operating efficiency. With development, total processing space does not increase. Instead, as the operational component becomes more efficient, more space remains for short-term storage (STSS). Case has expressed his concept of "executive processing space" in the following formula.

$$\text{TOTAL PROCESSING SPACE} = \text{OPERATING SPACE} + \text{STSS}$$

Case suggests two factors that contribute to increased efficiency in operating space - which leaves more room for short-term storage space. These two factors are specific practice and physiological-maturational changes. Specific practice improves the efficiency of the operational capacity but imposes a ceiling effect at various stages of development (Kurland, cited in Case, 1985). This leaves the maturational factor to be examined. Case has suggested that the physiological-maturational changes that allow for STSS are most likely due to myelination of nerve cells.

It is generally agreed that myelin has two primary functions. 1) it acts as an insulator and 2) increases the speed of neuronal

transmission (Peele, 1977). With these properties in mind, Case (1985) has hypothesized that in the absence of myelin, there could be leakage and disruption of messages to other nerve fibres resulting in less focus in the direction of the transmission. Conduction speed along the nerve would also be reduced. Thus the space for operational processing would increase reducing the space available for STSS.

Case's hypothesis that myelination accounts for the increase in STSS is not grounded in a great deal of experimental data as we shall see. While he acknowledges other physiological factors to be in evidence, he has focused specifically on myelin.

Neurophysiological Development

Neurophysiological development that occurs with maturation consists of several factors which are difficult to isolate on normal subjects with existing technology. These factors include biochemical maturation of neurons and glial cells, myelination, formations of synapses, and an increase in dendritic and axonal branches (Holmes, 1986). According to part of Hebb's theory, (cited in Case, 1985) when learning takes place, a chemical change occurs in the synapses between neurons such that a

stimulus is more likely to trigger a correct response. Kandel, (1979) has observed this experimentally and stated:

Both development and learning involve functional changes in the nervous system and therefore changes in the effectiveness of synapses and in other properties of neurons. (p. 67)

More recently, Holmes (1986) has reviewed developmental changes occurring in the newborn brain from the third trimester through the first two years postnatally. Most of these studies have been done with animal subjects. With maturation the neurons of the brain fire with increased spontaneity and more repetitiveness. Dendrites are projections that arise from the cell body and axons are long single nerve processes that extend from the axon hillock. With a maturing brain, there is an increase in axonal and dendritic connections and branches. The number and shape of these dendritic connections continues at least to seven years of age (Purpura, cited in Holmes, 1986). The increased dendritic connections allow for increased synaptic activity of both electrical and chemical types. Biochemical changes in the maturing brain parallel the development of dendrites, axons and synapses. Part of the biochemical change includes protein and its various components. Simply stated, "neurotransmitter concentrations increase with age" (Holmes, 1986, p.228). Electrical activity in the maturing brain is enhanced by the development of myelinated axons which increase the conduction

properties of the axon. In the immature central nervous system of the rat, slow conduction properties existed in poorly myelinated axons (Foster, Connors, Waxman, cited in Holmes, 1986).

Myelin consists of spiral layers of lipoproteins one to five microns thick that surround some nerve fibres in the central and peripheral nervous system. In the central nervous system myelin layers arise from oligodendroglia cells. In the peripheral nervous system, it is the Schwann cells that produce the myelin sheath. Each myelin segment is produced and supported by a single cell. Some nerve fibres are myelinated, others have a thin layer of myelin and still others are unmyelinated.

In a nerve fibre, flow of electrical current through adjacent parts of the axon membrane results in impulse transmission along the axon. Myelin insulates the outside of the axonal membrane from external current flow. In between the myelin segments are nodes. Instead of current flowing to immediately adjacent areas of axonal membrane it must go to the next node. Thus, in a myelinated axon current flow (i.e., the nerve impulse) travels further along the axon in a given amount of time than is the case for an unmyelinated axon (Garoutte, 1983; Chusid, 1982).

There are two components to myelination: a maturational one which consists of thickening of the sheath at its existing length

and a growth component, which consists of the appearance of myelin in conjunction with continued growth in nerve fibre length (Dobbing & Sands, 1973). The process of growth in the central nervous system can be estimated by the amount and location of myelin present in the system at different times during development.

Yakovlev and Lecours (1967) explored the cycles of myelination by staining specimens of cerebra. Using the Loyez staining method, they developed a graph indicating the approximate age at which myelination occurs in various nerve fibre systems. They discovered that myelin develops in an orderly sequence maturing at different times for different areas within the central nervous system. Parts of the central nervous system reach functional maturity early, while other pathways continue to develop into adulthood (DeKaban, 1970; Rorke & Riggs, 1969).

Examples of systems myelinating at different times are (a) the sensory systems of the spinal cord which show myelin growth to six months postnatally and (b) somasthetic pathways which show increased myelination at eight months pre-natally which continues to myelinate to the cortex until two years. The major growth of visual change takes place from birth to six months. The auditory system is the latest of the three major sensory systems to develop myelin as it begins at birth and reaches functional

According to Allison and Hume (1981) the neural generators of N14 are the dorsal column medial lemniscus system and the generator of N20 is the primary somatosensory cortex (Desmedt & Cheron, 1981). The P22 component arises in the parietal sensory cortex (Chiappa, 1983) (See Fig. 1).

Holmes (1986) states "the morphological, biochemical, and physiological maturation of the central nervous system is paralleled by distinct developmental changes in the EEG and evoked potentials (EP's)" (page 9). Although this makes it possible to measure general maturational changes that occur in the central nervous system, few studies have correlated specific changes with developmental changes that occur in EP's with age.

Non-invasive techniques estimating neurologic function in humans have recently become available. As technical equipment becomes more sophisticated, it becomes possible to measure developmental changes that occur in neural tissue more accurately. One of the most frequently used non-invasive methods of measuring changes in the nervous system is the somatosensory evoked potential.

Somatosensory Evoked Potentials

According to Licht(1980), by the late 1960's medical technology

had advanced to the point that conduction velocity studies of nerves became increasingly popular as a research project. Chiappa (1983) stated that evoked potentials (where latency times can be measured) began to have definite clinical utility by the early seventies as attention was given to short latency components. Human evoked potentials have been studied for many years but there is limited consensus on recording techniques or on the precise neuroanatomic correlates. More data is available on visual evoked potentials and brain stem auditory evoked potentials as they are more frequently used in clinical neurology.

A somatosensory evoked potential measures changes in electrical potential generated by activity in neurons in somatosensory pathways including peripheral nerve, spinal cord, brain stem and cortex in response to electrical stimulation of a peripheral nerve (See Fig. 1). Different somatosensory evoked potential components represent nerve activity at different points in the nervous system and allow measurement of conduction times between various brain structures. Evoked potential recordings are

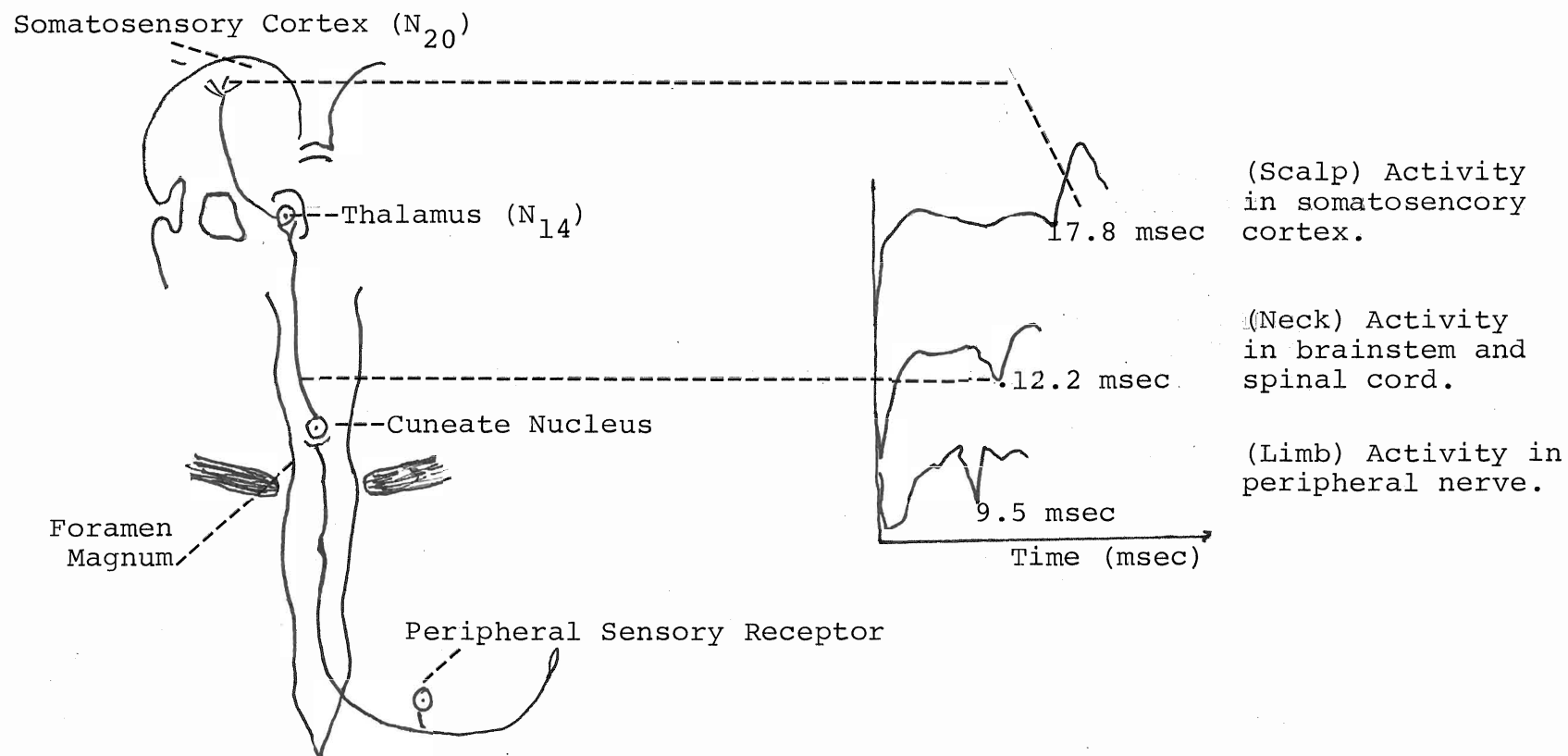


Fig. 1 - Origins Of Electrical Activity Along The Somatosensory Pathway.

displayed as wave forms with peaks representing the response of neurons at different locations along the nerve pathway. Absolute latency is the time required for the message to travel from the stimulus point to the somatosensory cortex. Interpeak latency is the absolute latency time minus the time from stimulus to the previous peak. With development and neuronal maturation there is a corresponding increase in the speed of transmission.

Transmission speed along the nerve fibre is measured by conduction times or conduction velocities. Gamstorp (1963) studied the changes in conduction velocities of the ulnar and median nerves of the arm and the peroneal nerve of the leg. Subjects were normal infants, children, and adolescents. In newborns, the conduction velocities of all three nerves were found to be half that of adults. The value for the ulnar nerve increased rapidly during the first three years. The median nerve value increased slowly before one year of age but accelerated rapidly after three years continuing into adolescence. This is the nerve that directs the late appearing precise movements of the thumb.

In similar testing of normal subjects for motor conduction velocity in the posterior tibial and median nerves, Martinez, Ferrer, Conde, Bernacer (1978) found no significant changes in the tibial nerve after four years of age but significant changes

in the median nerve values took place between 4 and 11 years of age. Wagner and Buchthal (1972) found distal sensory conduction velocity in the median nerve to increase from 55 m/s at 2 years of age to the adult average of 62m/s at 12 years of age. The findings of the preceding studies contradict more recent work of Desmedt, Brunko, Debecker (1976) who found conduction velocities in median nerves to reach adult values by 12 to 18 months of age.

In studies of infants and children 1 month to 13 years responding to spinal evoked responses (Cracco & Cracco, 1975, 1978, 1979) velocities increased with age reaching adult values after four years. Desmedt et al. (1976) found conduction velocities in the central lemniscal somatosensory pathways reached adult values between five and seven years of age. Dorfman and Bosley (1979) investigated age related changes in peripheral and central nerve conduction velocities. Their subjects were 60 to 86 years of age and a control group of younger people. Results showed relatively stable spinal sensory conduction velocities from 18 to 60 years and a sharp decline in conduction velocities after 60 years.

Hume, Cant, Shaw, and Cowan (1982) studied 83 normal subjects 10-79 years of age. They recorded somatosensory evoked potentials elicited by median nerve stimulation. Results showed

central conduction times (N14-N20) remained constant between 10 and 49 years of age. Mean central conduction time of subjects 50 years and over was significantly longer than that of younger subjects.

According to Nakanishi, Tamaki, Mizusawa, Akatsuka, and Kinoshita (1986), a linear relationship between nerve conduction velocity and diameter of myelinated nerve fibres is generally accepted. The increase in the speed of conduction that accompanies maturation in peripheral nerve and spinal cord is probably related to the increasing fibre diameter and progressive myelination that accompanies maturation (Cracco and Cracco, 1982). Lee, Chung, Chung, and Coggeshall (1986) corroborated the above by finding a linear relation between the diameter of the peripheral axon and the conduction velocity of the impulses carried by these axons. These studies indicate that increased conduction speed that occurs with maturation in the peripheral nervous system is probably due to thickening of the myelin sheath and the increased diameter of the axon.

The literature shows clearly that conduction times and velocities vary with age in human subjects. With age, conduction times decrease and conduction velocities increase. Hume et al. (1982), and Dorfman and Bosley (1979) indicate conduction times begin to

increase and velocities decrease around 50 years of age. Depending on which nerve was stimulated, the adult values were reached at ages varying between 5 and 12 years.

In discussing the speed at which an impulse travels along the nerve, an explanation of conduction time and conduction velocity is helpful. Conduction time is the time difference between two specific components. The distance is unknown but assumed to be consistent. Conduction velocity results from recordings usually taken from two points on a limb. The time for the peak to go from A to B is divided by the distance from A to B resulting in m/s units.

When conduction times were taken in the peripheral nervous system, arm length and height, which are related to age, confound the latency times (Hume et al., 1982). However, when differences in interpeak latencies are taken (i.e., N20-N14) the time is independent of length and height (Hume & Cant, 1978). Hume et al. (1982) also showed there was no correlation between central conduction time and the sagittal and transverse diameters of the head when subjects 10 years to 79 years were studied. Based on the above studies, it seemed appropriate to measure interpeak latencies N14 - N20 using conduction times (ms) between 3- and 11-year-old children. Due to the obvious height and length

differences in 3-and 11-year-olds, the measurement of central conduction times (N14-N20) were, according to Hume, the most accurate measure to use in this study and conduction velocity was the appropriate method to measure speed in the peripheral nervous system.

While studies of normal central conduction times are available within age groupings 1 to 8 years, 18 to 40 years (Gilmore et al., 1985; Cracco & Cracco, 1982) 10 to 29 years (Hume et al., 1982; Cracco & Cracco & Stovelove, 1979; Cracco, Cracco & Graziani, 1975), there are no studies which deal with age specific normal central conduction times. Normative data for specific age groups is not available. Therefore it was necessary to record data from 3-year-old and 11-year-old children.

Towards a Correlation

From the preceding literature review, we can see that it is possible to measure a component of physiological development by using evoked potentials and recording conduction times and velocities. The evoked potential recordings can be made by non-invasive techniques on alert human subjects. With age, both the speed of conduction and maturational changes have been correlated. Recorded times are indicative of a composite neurological maturation but cannot be related specifically to any

one of the biochemical, axonal, synaptic or myelin changes that occur.

Intelligence and short-term memory or storage space have been linked for years (Humphreys, Lynch, Ravelle, & Hall, 1983). Present day IQ tests such as the Stanford-Binet and the Wechsler Intelligence Scale for Children continue to include a digit span task. Developmental differences in memory span have been reviewed by Dempster (1981). In this review, he examined possible sources of developmental differences in performance. Evidence seemed to show that mnemonic strategies and a higher order of informational chunks were involved in the growth of STSS. As well, there were other unexplained factors at work (Dempster, 1981; Huttenlocker & Burke, 1976; Case, 1985). There has been such a strong relationship between STSS and intellectual and developmental differences that it is reasonable to employ STSS as an index of intellectual development.

Howard and Polich (1985) tested normal children 5 to 14 years and adults 21 to 39 years of age for later positive components (300 ms) of the auditory evoked response (P300 latencies) and memory span development. They used an evoked response potential and the Wechsler Intelligence Scale for Adults. The P300 latency was

positively correlated with memory span. This led them to hypothesize that the primary cause of memory span increase was the increased stimulus processing capability that occurs with development. There was no evidence, however, of any studies which attempted to correlate central conduction times and peripheral conduction velocities with short-term storage space levels (or items to be remembered).

Hypothesis

It was hypothesized that conduction speeds and the number of items retained in memory would increase with age and conduction speeds and memory scores would show a significant correlation.

CHAPTER THREE

Procedures

Selection of Subjects

Three groups of normally healthy children, all of whom volunteered to participate served as subjects for this study. The subjects had no known neurological disorders affecting the central or peripheral nervous system.

Group I (n=13) consisted of children 11 years of age ($\bar{M} = 11.5$ years, $SD \pm .30$) (7 males, 6 females) who achieved a scaled score of 12 and above on the digit span - a sub-test of the WISC-R.

Group II (n=15) consisted of children 11 years of age ($\bar{M} = 11.2$, $SD \pm .26$) (11 males, 4 females) who achieved a scaled score of 7 and below on the digit span sub-test of the WISC-R. The children in this group all happened to be in special education or adaptation classes and were all labeled "learning disabled" by their respective school evaluations.

Group III (n=12) consisted of children three years of age (mean

age 3.5, SD \pm .27) (6 male, 6 female). Informed consent was obtained from the parents of all subjects (See appendix 4).

Martinez et al. (1978) found significant changes occur in conduction velocity between 4 and 11 years of age using median nerve stimulation. Since this study used median nerve stimulation, it seemed appropriate to test the subjects just prior to reaching four years. Other studies of evoked responses suggest adult values are reached after four years (Cracco & Cracco, 1979). Desmedt et al. (1976) found conduction velocities to reach adult values between five and seven years. It was felt 3 years of age was the earliest age at which cooperation of the subjects on the required tests could be expected. It was also the maximum age prior to reaching adult conduction times according to some researchers.

Eleven-year-old children were selected as subjects because conduction velocities in the median nerve reach adult values about this time (Martinez et al., 1978). Hume et al. (1982) found central conduction times elicited by median nerve stimulation remained constant between 10 and 49 years of age. Dorfman and Bosley (1979) reported relatively stable conduction velocities from 18 to 60 years. Eleven years of age appeared to be the time at which the child was reaching adult values for speed of conduction.

The two groups of 11-year-olds were selected on the basis of scaled scores on the digit span sub-test of the WISC-R. One group achieved scores of 12 or more and the other group had scores of 7 or less, reflecting short-term memory performance difficulties. All subjects with 7 or less on the WISC-R also happened to be in special classes for children with learning disabilities. This was not a criterion for the study due to the difficulty in defining "learning disabled".

Due to the obvious developmental differences expected between 3- and 11-year-olds, it was decided to have a between group comparison of 11-year-olds as well. Thus, the inclusion of the 11-year-olds on the basis of poor short-term memory scores in order to measure the influence of physiological development on their performance. The second group of 11-year-olds were given a non-verbal IQ test-the Culture Fair test of "g" in order to obtain a measure of their IQ scores but this data was not included in the statistical analysis.

Memory Tests

The digit span test a sub-test of the WISC-R, was administered to all 11-year-olds as directed in the WISC-R handbook. The test

consisted of two parts administered separately - Digits Forward and Digits Backwards. Two trials were given at each item and the digits were presented verbally at the rate of one per second. The child was directed to listen carefully and repeat the numbers spoken by the researcher. Testing was discontinued after failure on both trials of any item. Each item was scored 2, 1, or 0 and the sum of Digits Forward and Digits Backwards was totalled. Each raw score total was then referred to equivalents on tables of scaled scores. Subjects were selected on the basis of achieving a scaled score of 12 and above for group I and a scaled score of 7 and below for group II. According to Kaufman (Chapter 4, page 105) the digit span test is subject to the influence of attention span, anxiety, distractibility and (rehearsal strategies). The unique ability measured is short-term memory (auditory). Low scaled scores on this test have been correlated with difficulties in academic work.

Measurement of short-term storage space items for all three groups of subjects took place in the home of each child where it was felt he would be most comfortable. The experimental memory tasks were of a sensory motor nature and consisted of two tests. One test consisted of fine motor items and the second, gross motor items (Appendix 2 and 3). The fine motor memory test was

an experimental one designed by Case and modified by the researcher to accommodate the abilities of 3-year-old children. The gross motor memory test was devised by the researcher as indicative of items cited by Seaman (1982) that could be performed by a normal 3-year-old. Only the memory level was being scored and not the quality of the reproduction. Before the testing for memory was begun, care was taken to see that the subject could perform each of the individual items. Three practices were given to each subject prior to testing. For the 3-year-old child, the fine motor test was made into a game of "magic code". The child was asked to hold his hands together (in order to eliminate practice) while the researcher visually presented the "magic code". Then the child was asked to repeat it. Items on the fine motor test were presented for four seconds each. This was not possible on the gross motor test due to the nature of the items (Appendix 3). All items were visually presented.

Memory items were scored by level both liberally (not in order) and conservatively (in given order). Three trials were given at each level and the subject was required to be correct on two out of three in the set in order to attain that level. Fine motor items and gross motor items were scored separately. For example, when the child had shown he could complete the individual operations, the tester gave the subject an operation plus one

item to be committed to STSS at level one. Three trials were permitted at this level. When two of the three were correct, the subject progressed to the next level where an operation plus two items were presented.

According to Case (1985) there are four criteria to be met in order to have a valid psychological test indicative of a subject's STSS. These criteria are: 1) it must require the subject to execute a series of formally identical operations; 2) it must permit the developmental level of these operations to be specified (sensorimotor in this study); 3) it must require that a pointer to each prior operation be stored while each subsequent operation is executed, thus producing an increasing executive processing load at each step; 4) it must permit the experimenter to determine the number of such steps which subjects can execute and hence the number of pointers they can store before their executive processing space becomes overloaded. The items in this study which measure STSS fulfilled the above criteria as proposed by Case (p. 309).

Somatosensory Evoked Potential Procedure

Since the memory tests were of a visual sensory-motor nature, it was decided that somatosensory evoked potential recording by stimulation of the median nerve would integrate a measure of

central conduction time with a central measure of development.

Somatosensory evoked potential recordings were taken at the University of Alberta Hospital. All recordings were performed on the same machine (Nicolet 1003) and were administered by either one of two experienced technicians at the University Hospital Evoked Potential laboratory. Each child was alert, lying comfortably in a quiet room where the temperature was 20 - 22 C at the time of testing. Mothers of 3-year-olds were present with their own child and the researcher was in attendance at all the evoked potential sessions. Childrens books were used to keep the child occupied while preparations were done.

Measurements were taken from theinion to the nasion and between the zygomatic arches. The intersection (vertex) of these two lines at the top of the scalp was marked. Twenty percent of the distance from the vertex to the zygomatic arch was calculated and a mark was made on the transverse axis on either side of the vertex at the calculated distance. Electrodes were placed 2 cm posterior to these points marked on the transverse axis over the primary sensory cortex and labeled C3' and C4' (see Fig. 2). Electrodes were also placed over the second cervical vertebra, at the collarbone (Erb's point) and over the median nerve at the wrist. At the wrist, the anode was placed about 1 cm from the wrist crease and the cathode was placed 3 cm proximal to the

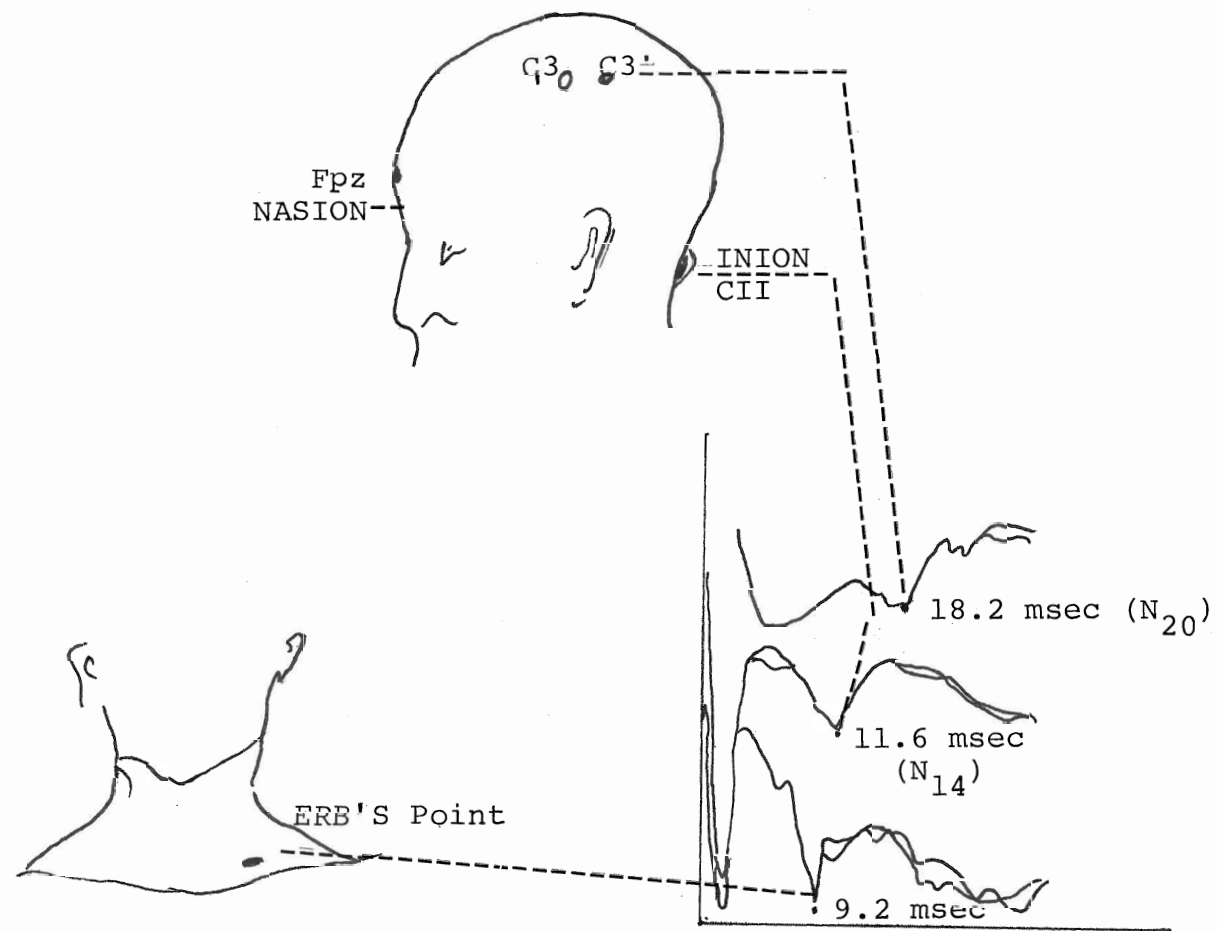


Fig. 2 - Recording Points Along The Somatosensory Pathway.

anode. The recording system ground was placed on the stimulated forearm proximal to the stimulus electrodes (Fig. 5).

Electrodes were applied with collodian. Collodian was dried with compressed air and the electrolyte solution was injected through a hole in the electrode using a blunt tipped syringe. Skin to electrode impedance was kept at less than five kilohms to insure reliable recordings. Acetone was used to dissolve collodian during removal of electrodes.

A Nicolet 1003 constant current stimulator presented a square wave impulse of 200 microseconds duration at a constant rate of 3.1 Hz to the median nerve. The stimulus and trigger to the computer averager (CA 1000) were synchronized by a pulse generator. The stimulus was delivered at a rate of 3.1/sec, applied to the skin over the median nerve at the wrist via two electrodes. Stimulus intensity was adjusted to that level which produced a thumb twitch. For each arm, 2 averages of 250 responses each were recorded. There was a total of 1,000 responses for each subject. Tin cup electrodes, 6 mm, in diameter were applied at Erb's point (see Fig. 2) and over the second cervical vertebra. Scalp electrodes were placed over the somatosensory cortex (C3' and C4') and at Fpz on the forehead according to the international 10 - 20 electrode system (Epstein & Andriola 1983). Fpz was the reference electrode. A ground

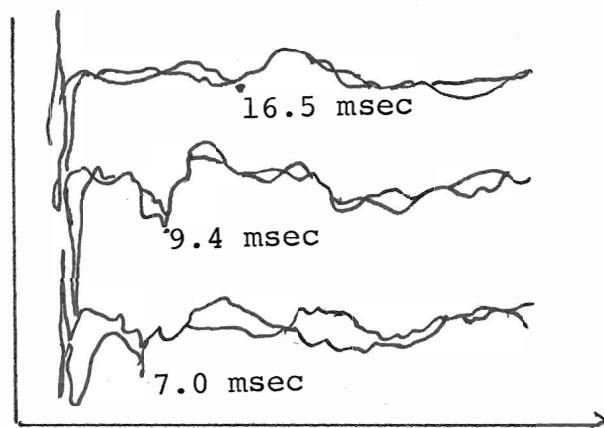


Fig. 3 SSEP - 3-Year-Old Time (msec)

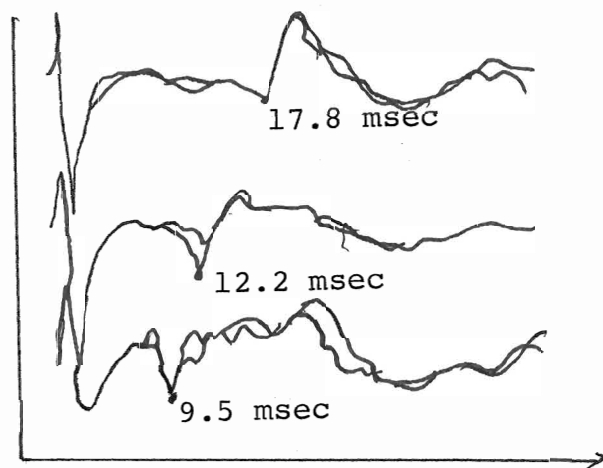


Fig. 4 SSEP - 11-Year-Old Time (msec)

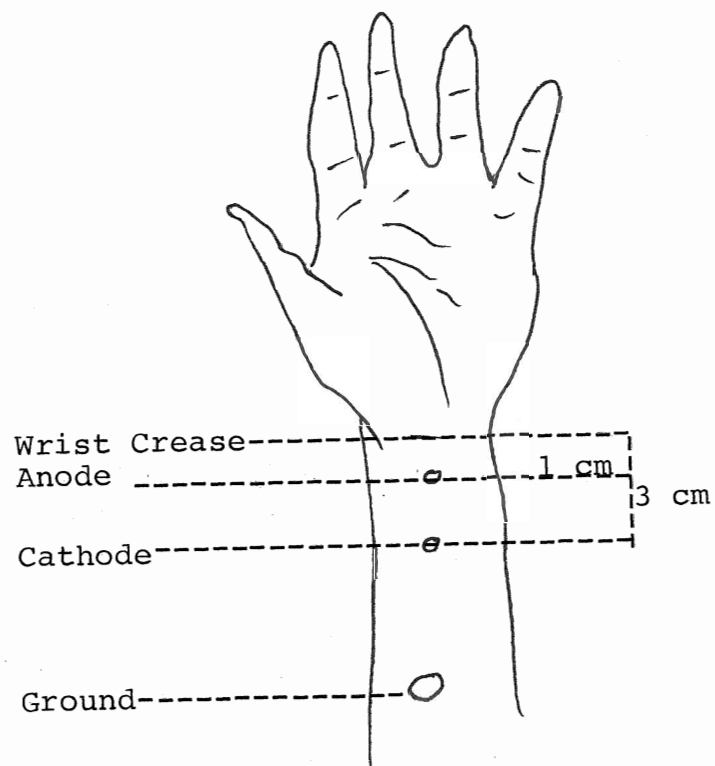


Fig. 5 Median Nerve Stimulation

electrode was placed on the forearm proximal to the stimulating electrodes. The output from each electrode was led into amplifiers (Nicolet HGA-200A) with a frequency bandpass of 30-1500Hz. Total sweep time used was 40 milliseconds. All inputs were monitored on an oscilloscope and computer averaging was discontinued when prominent movement artifacts appeared. The whole procedure was explained to each child by the researcher at the first meeting prior to the testing and again by the technician as each step of the procedure was carried out. Each child was well acquainted with the procedure by the time of testing.

Recording sites were Erb's point located at mid-clavicle (Epstein & Andriola, 1983), the second cervical vertebra (CII), and contralateral somatosensory cortex. All recording electrodes were referred to the Fpz. Using montage Erb's-Fpz, CII-Fpz and C3' or C4'-Fpz the x-y plotter showed negative voltages at Erb's point, spinal cord and cortical electrode sites relative to the forehead site. These appeared as downward deflections (see Fig. 3 and 4). P22 from the cortex showed as an upward positive voltage.

The electrode at Erb's point (collarbone) records a negative peak arising from the action potentials occurring in the median nerve

as it courses through the brachial plexus. The second potential, N14, occurs at the CII recording site and is related to discharge cells in the dorsal column nuclei, located in the medulla, that project to the thalamus (Cracco & Cracco, 1976; Hume & Cant, 1978; Mauguiere & Courjon, 1981; Sances & Larson et al., 1978).

The N20 component recorded from the scalp over the somatosensory cortex is generally agreed to originate in the primary somatosensory cortex (Allison and Hume, 1981; Hume & Cant, 1978). N14, N20 and P22 denote latency times of 14 ms, 20 and 22 ms found in normal adults. Conduction time to P22 - a positive wave arising from later cortical activity was also recorded. For this study interpeak latency times were taken from CII (N14) to the somatosensory cortex C3' and C4' (N20) and N14 to the later cortical wave P22. This time is recorded as central conduction time. When differences in interpeak latencies are taken (i.e., N20 minus N14) the time recorded is independent of arm length and subject's height (Hume & Cant, 1978) so we have a basis of comparison for CCT between 3- and 11-year-olds (See Fig. 2).

The Nicolet recorder in the EEG laboratory at the University of Alberta Hospital was calibrated to electronically record times for Erb's point, the N14 wave and the P22 wave. Generally central conduction time refers to interpeak latency between N14 and N20. In order to maintain this standard, the N20 latency component was

measured on all subjects with an engineering micrometer from hard copy plots of the somatosensory evoked potential. Every N20 component latency was measured at least twice and found to be consistent for validation purposes.

The conduction times recorded in the peripheral nervous system (i.e., stimulus to Erb's point) are related to the subjects' arm length and height which are in turn related to age. These factors confound the latency times (Hume et al., 1982). In order to correct for the disparity in length and height between 3- and 11-year-olds, peripheral conduction velocities were calculated by dividing arm length by time from stimulus to Erb's point. Arm length was measured from the cathode to the elbow crease, from elbow crease to shoulder point, from shoulder point to Erb's point.

Comparisons

This study proposed to make developmental comparisons between 3- and 11-year-olds using short-term memory scores, central conduction times, and peripheral conduction velocities as dependent variables with the independent variable being age.

Between group comparisons were made with the two 11-year-old groups with respect to scores achieved on the sensory-motor

memory tests, the central conduction times and peripheral conduction velocities. The relationship between levels achieved on the memory tests indicating cognitive development and central conduction times indicating physiological development was examined using a Pearson product correlation. These comparisons were made between groups as well as within each of the three groups. Comparisons in CCT between right and left median nerve stimulation were made using a paired t test.

Two-tailed t tests were applied to all comparisons. Linear regression analysis was used to examine the relationship between fine motor memory level and central conduction time in 3-year-olds and 11-year-olds with normal memory scores. A similar analysis was used to look at the relationship between gross motor memory levels and central conduction times, both between groups and within groups.

Results and Discussion

The subjects (N=40) for this study consisted of children 3 and 11 years of age. The 11-year-olds consisted of two groups: one which achieved 12 or more on the digit span sub test of the WISC-R, the other group achieved 7 or less on the same test.

All three groups were tested on the same fine and gross motor short-term memory tests. Resulting scores were indicative of cognitive development. All subjects submitted to somatosensory evoked potential tests which allowed the recording of transmission speeds in the peripheral nervous system and the central nervous system (specifically N14-N20, and N14 - P22). These recordings allow a measure of general physiological development in the nervous system.

Comparisons of cognitive development and physiological development were made using t-tests and a linear regression analysis. Memory scores were indicative of cognitive development and conduction speeds were indicative of physiological development. Comparisons were made between 3-and 11-year-olds and between the 11-year-old groups which had different memory scores on the digit span of the WISC-R.

As predicted, there were significant developmental differences between 3-year-olds and 11-year-olds who scored 12 or more on the digit span test. These differences were: (1) 11-year-old children had significantly faster central conduction times ($\bar{M}=5.7\text{ms}$) than 3-year-olds ($\bar{M}=6.69\text{ms}$) $t(25) = 8.34$ $p<.01$ (see Fig. 6 and 7); (2) 11-year-old children could remember more than 3-year-old children on both the gross and fine motor memory tasks

11-year-old ($\underline{M}=3.3$) 3-year-old ($\underline{M}=1.5$) $\underline{p}<.01$, 11-year-old ($\underline{M}=3.0$) 3-year-old ($\underline{M}=1.16$) $\underline{p}<.01$ (see Fig. 8 and 9). Memory score (gross and fine motor) comparisons between 11-year-olds with poor memory scores were significantly different to those of 3-year-olds $\underline{t}(25)= 2.78$ $\underline{p}<.01$; 3) peripheral conduction velocities were significantly faster in the 11-year-old group when compared with 3-year-olds $\underline{p}<.01$ (see Fig. 10).

In all comparisons the 11-year-olds scored higher on memory levels or had faster conduction times. Between group comparisons with 11-year-olds with high memory scores on the WISC-R and low memory scores showed: 1) no significant differences in central conduction times; 2) differences in motor memory levels $\underline{p}<.01$ with the high WISC-R digit span scorers receiving higher scores on the gross and fine motor memory tests (see Fig. 8 and 9); 3) there were no significant differences between the 11-year-old groups when peripheral conduction velocities were calculated. There were no significant differences within any group between conduction times recorded on the right or left hand sides using a paired \underline{t} test.

Linear regression lines were calculated for 3- and 11-year-olds (12 or more on digit span) with the "Y" axis denoting central conduction time and the "X" axis showing memory levels achieved

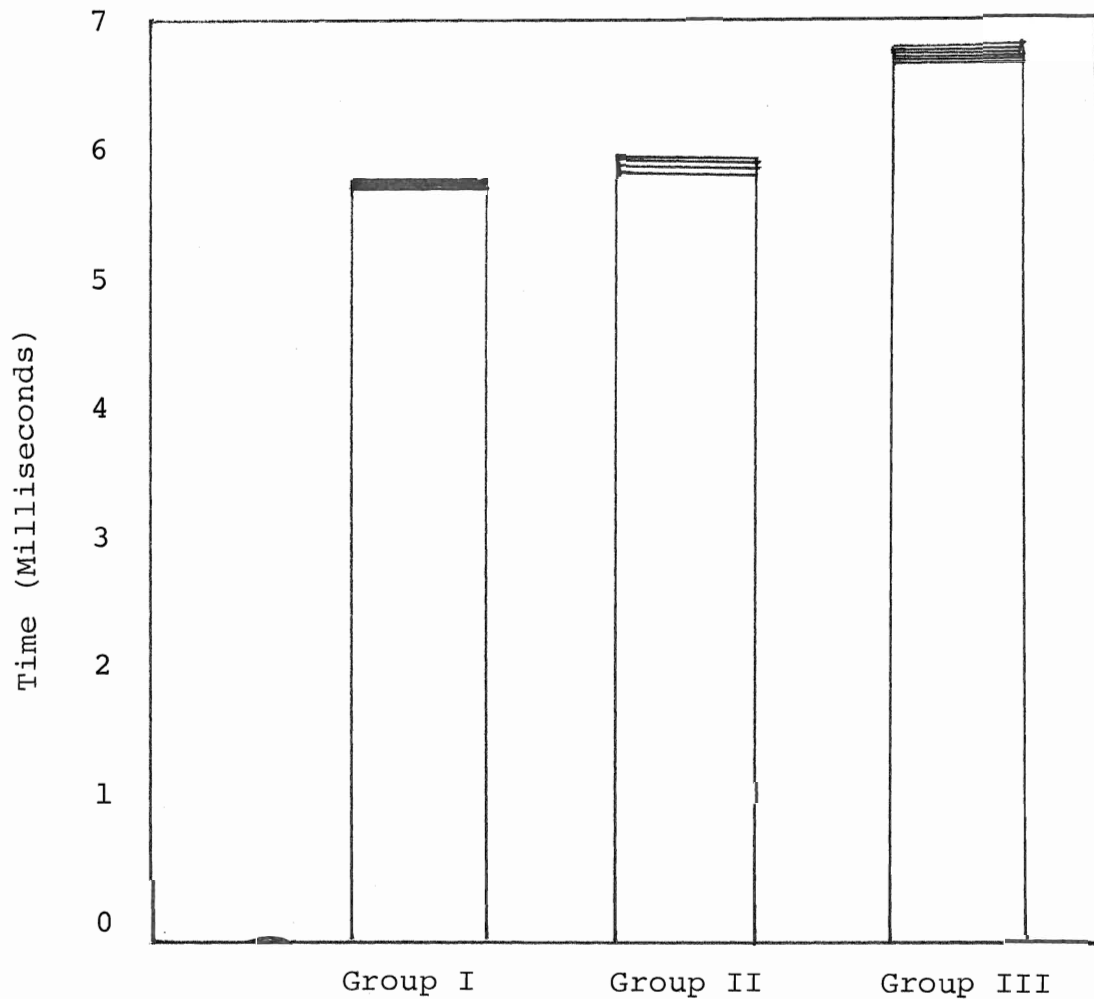


Fig. 6 - Central Conduction Times Of 3-Year-Old Children
N14-N20.

Group I - 11 Years - 12+ On Digit Span. CCT=5.7ms, SE=.059

Group II - 7 And Below On Digit Span. CCT=5.8ms, SE=.095

Group III - 3 Years. CCT=6.69ms, SE=.103

Standard Error.

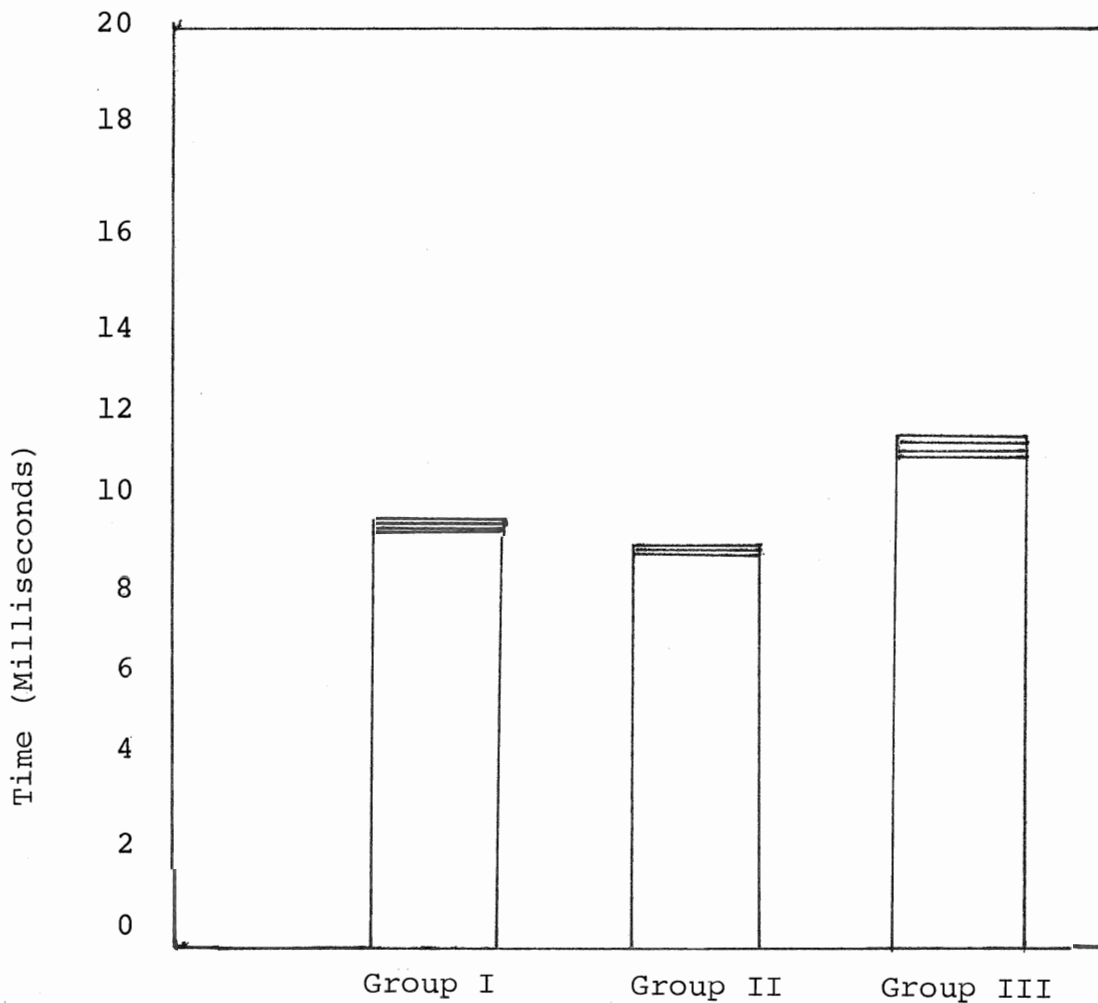



Fig. 7 - Central Conduction Times Of 3-Year-Old Children
N14-P22.

Group I - 11 Years - 12+ On Digt Span. CCT=8.9ms, SE=.220

Group II - 7 And Below On Digt Span. CCT=8.4ms, SE=.188

Group III - 3 Years. CCT=10.64ms, SE=.290

Standard Error 

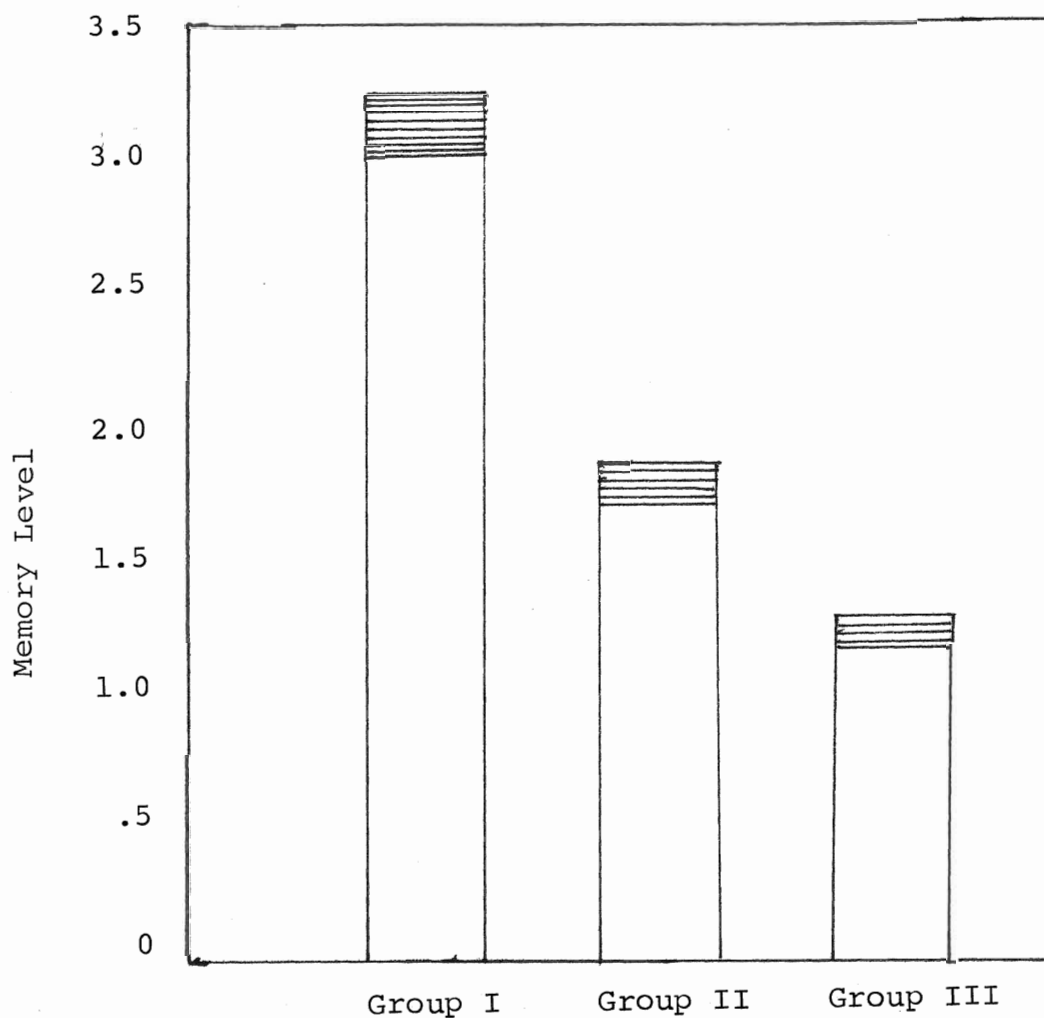
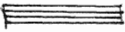


Fig. 8 - Fine Motor Memory Level Comparison.

Group I - 11 Years - 12+ On Digit Span.

Group II - 11 Years - 7 And Below On Digit Span.

Group III - 3 Years.

Standard Error 

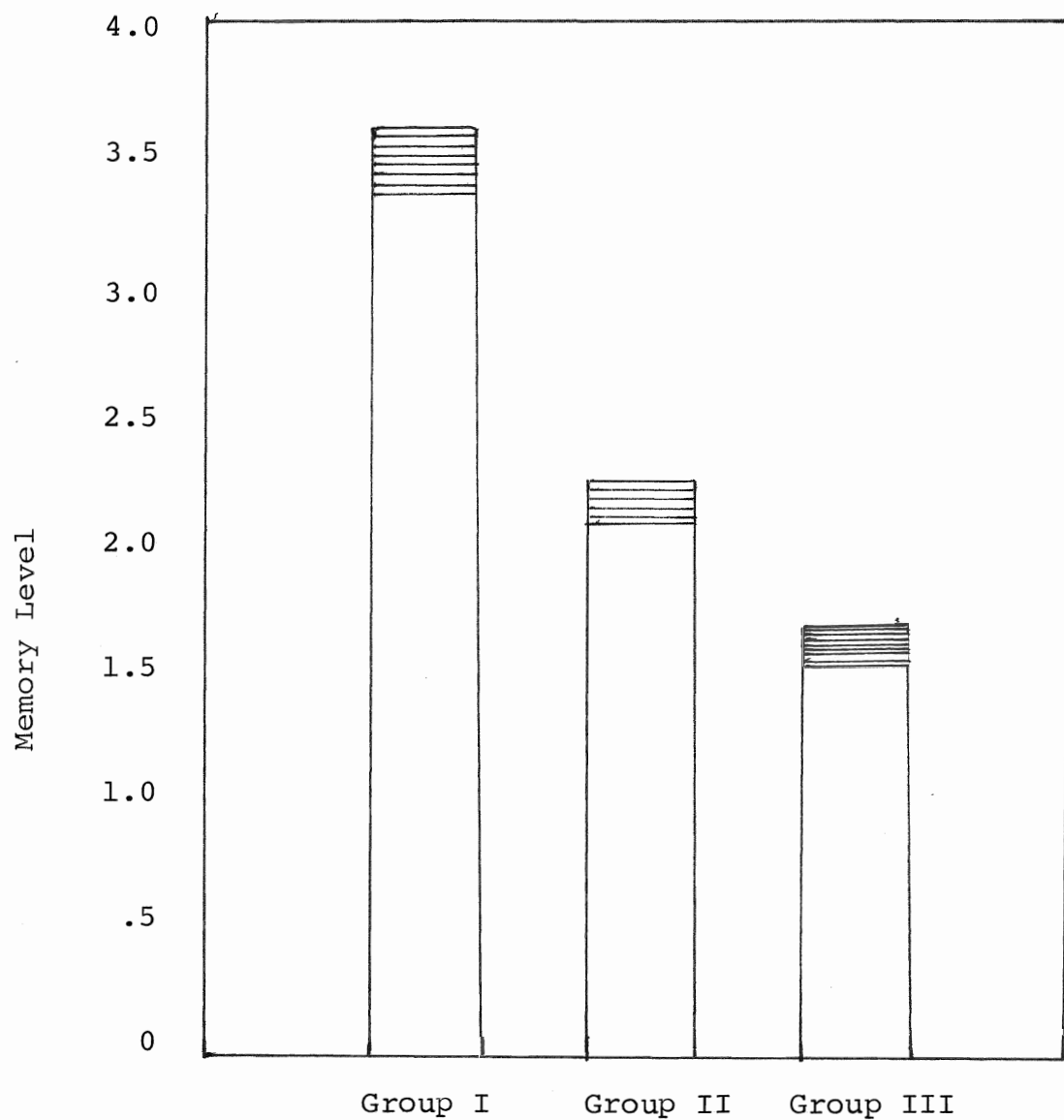
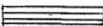


Fig. 9 - Gross Motor Memory Level Comparison

Group I - 11 Years - 12+ On Digit Span.

Group II - 11 Years - 7 and Below On Digit Span.

Group III - 3 years

Standard Error. 

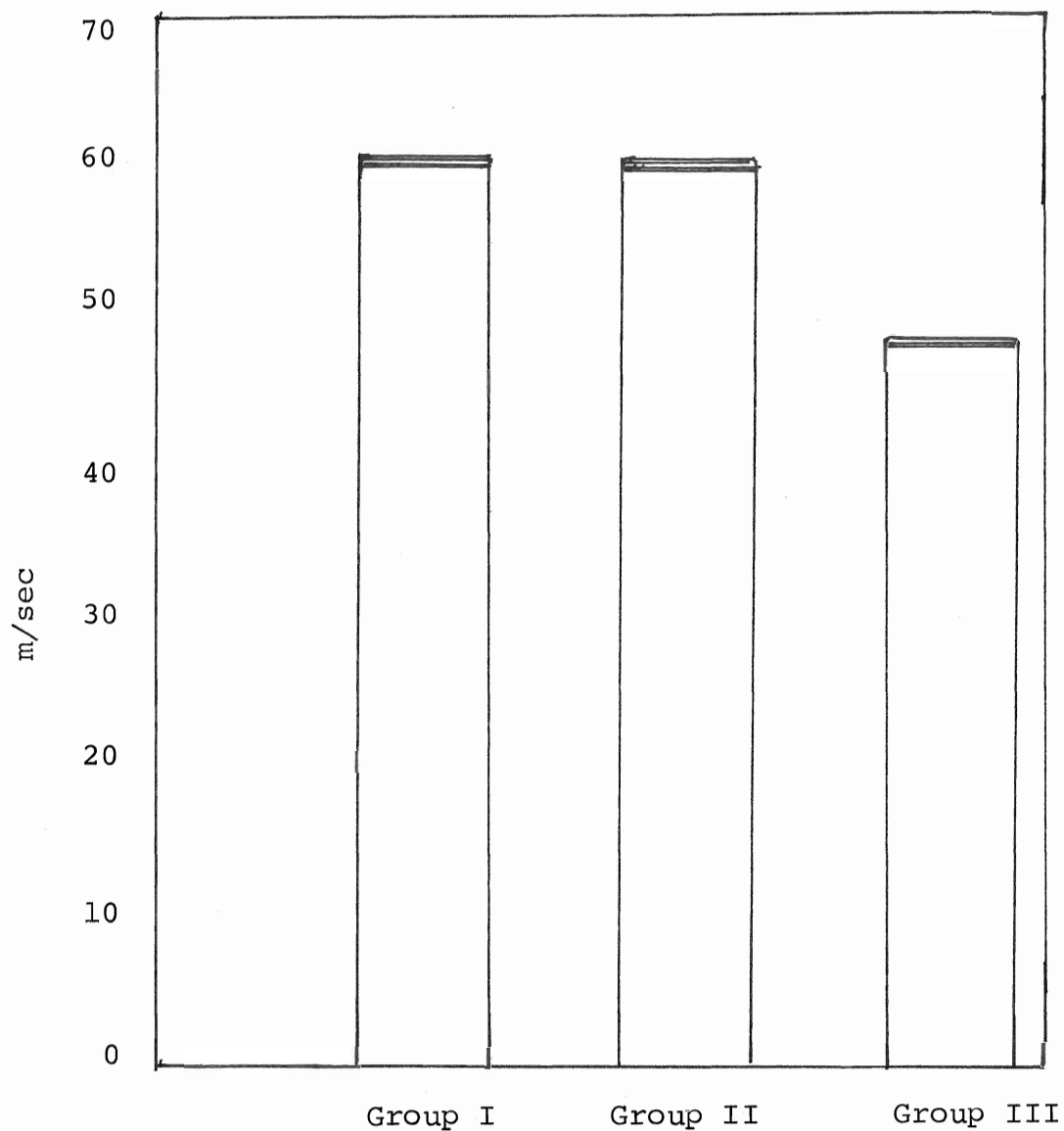


Fig. 10 - Peripheral Conduction Velocity Comparison.

Group I - 11 years - 12+ on Digit Span.

Group II - 7 and Below on Digit Span

Group III - 3 years

Standard Error

on either fine or gross motor tasks. All lines showed a significant inverse correlation between CCT and memory levels when a Pearson correlation was applied $r = -.67$, $r = -.69$, $p < .01$. As central conduction time decreased, memory levels increased (see Fig. 11 and 12). There was no significant correlation between achieved memory levels and CCT when 1) the 11-year-olds (7 or less on digit span) and 3-year-old groups were compared; 2) between the two 11-year-old groups; 3) within any one group.

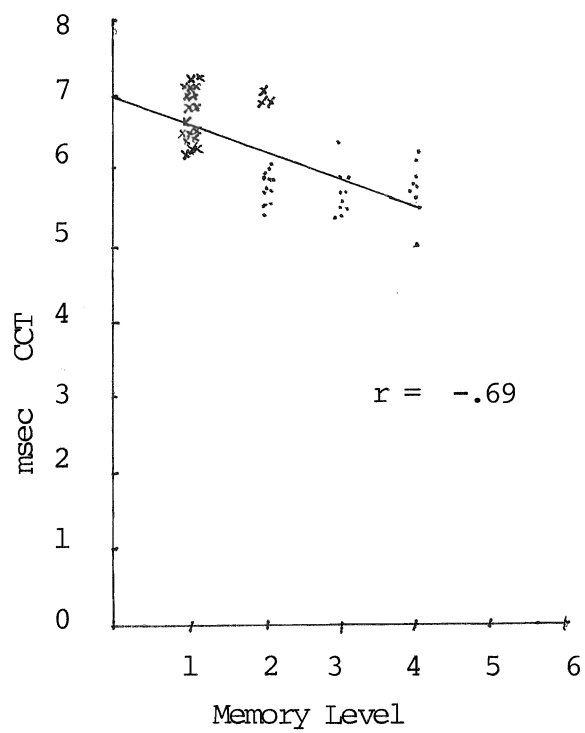
Consistent with the studies of Hume, 1982; Dorfman and Bosley, 1979; Cracco and Cracco, 1975, 1978, 1979, this study demonstrated developmental differences between 3-year-olds and 11-year-olds in central conduction times following median nerve stimulation $p < .01$. This present study was more specific than others as it focused on children who were 3 years old or 11 years old at the time of testing.

The significant differences that occurred between 3- and 11-year-olds in CCT and peripheral conduction velocity are probably due to the maturational changes that take place between 3 and 11 years. The significant difference in peripheral conduction velocity between 3- and 11-year-olds with median nerve stimulation supports the findings of Martinez et al. (1978). This increase in transmission speed along the nerve fibres is associated with myelin maturation which continues into adolescence (Martinez et

Correlation Of Central Conduction Time And Fine Motor
Memory Level In 3-Year-Old And 11-Year-Old Children.

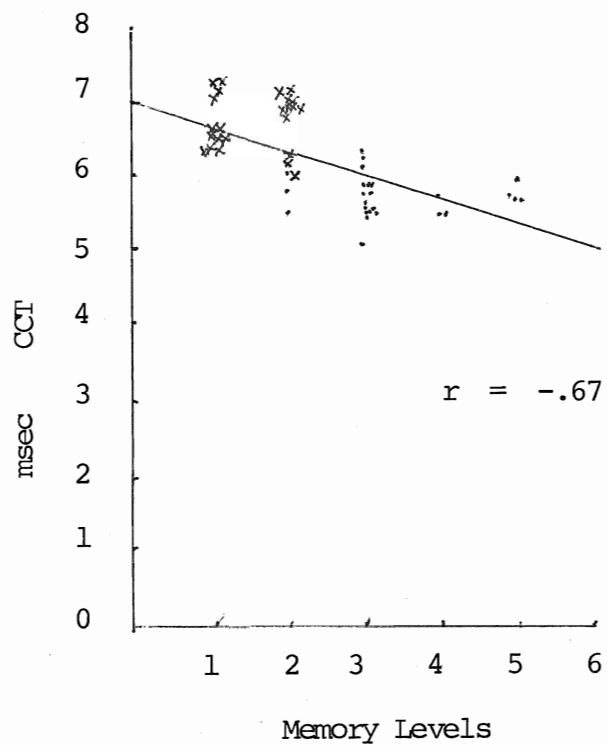
Legend 3 Year - x

11 Year - .



Correlation Of Central Conduction Time And Gross Motor
Memory Level In 3-Year-Old and 11-Year-Old Children.

Legend 3 Years - x
 11 Years - .



al., 1978; Schulte, 1974). Also, the CCT in this study parallel those found by J.B. Cracco for 3-year-olds 6ms-7ms (personal communication, June 16th, 1986). In this study CCT mean for 3-year-old children was 6.69 ms. Both of these times were derived from median nerve stimulation.

Similarly, J.B. Cracco has times of 4.5 ms to 5.5 ms for the adolescent and young adult. These times are slightly shorter than the 5.70 ms and 5.86 ms that the present study found for 11-year olds with high and low memory scores respectively. The difference can probably be attributed to the fact that Cracco has generalized the age group to adolescents and young adults while this study specifically tested 11-year-old children. The latter times are slightly longer indicating slower conduction between the N14-N20 peaks but are not significantly different. Findings were similar for the N14-P22 interpeak latency.

All three groups of children achieved higher scores on the gross motor memory items than on the fine motor items. Perhaps this was due to the fact that gross motor movements develop earlier than fine motor schemas.

The high scoring memory group of 11-year-olds scored at mean

level 3.0 for fine motor items and 3.3 for gross motor items. Scoring at level 3.0 meant one operation plus three items were remembered in STSS. On the same tasks 3-year-old mean scores were fine motor - 1.16 and gross motor - 1.50. Between 3 and 11 years, the number of items retained in short-term storage increased by 1.84 units on fine motor tasks and 1.80 units on gross motor tasks.

Between the 11-year-old age group there were no significant differences in any portion of the evoked potential tests of N14-N20, N14-P22 or peripheral conduction velocities even though there were significant differences in their achieved levels of STSS. The results of this study indicate that interpeak latency between N14 and N20 and N14 and P22 resulting from median nerve stimulation cannot be used to identify children with poor memory scores from age-matched peers with good memory scores. There is no indication of abnormality of the somatosensory afferent pathways.

Obrzut et al. (1987) have reviewed recent studies that use brain stem evoked responses in assessment of learning disabled children with age-matched peers. While these studies indicate significant differences in evoked responses between learning disabled children and age-matched normal controls they are inconclusive due to small sample size, variations in procedures and lack

of control populations. Some of these studies found electrophysiological differences between children with learning disabilities and others did not. The brain stem evoked response records activity generated in a different area of the brain than the somatosensory evoked potentials recorded here. The present study did not find significant neurological differences between children with low memory scores who happened to be in learning disabled classes and children in regular classes with high memory scores. Central nervous system storage and integration are the last areas of the brain to undergo myelination according to Yakovlev and Lecours (1967) and this continues into the third decade. If this is so, then 11-year-old conduction times are not indicative of adult values. In this case, more studies of normative data on age specific groups is required.

No significant difference was found in the peripheral conduction velocities between the two groups of 11-year-olds which indicates that the median nerve of the peripheral nervous system had matured to the same degree in both groups of children. Memory comparisons between the 11-year-old group were significantly different on both fine and gross motor tasks with the poor memory group scoring lower in both cases. The regression analysis of central conduction times and fine and gross motor memory scores for 3- and 11-year-olds showed reliable Pearson r values $r = -.67$, $r = -.69$. Between 3 and 11 years of age central conduction times

decrease and memory scores increase. The present study found a relationship between neurological maturation as measured by central conduction time and cognitive development as measured by fine and gross motor memory tests.

This result is consistent with the findings of Howard and Polich (1985) who found memory span increases correlated with P 300 peak latency decreases in normal children 5 to 15 years. Their study measured a later neural component using brain stem evoked response.

CHAPTER FOUR

Summary and Conclusions

This study was able to submit a single subject to tests that measured intellectual development (short-term storage space) and neurological development (central conduction time). A correlation was shown between short-term storage space and central conduction time but as there were only two specific age groups, 3 and 11, it is possible that intermediate points on the line might not correlate.

Developmental differences, both intellectual and physiological, that appeared in this study between 3-year-old children and 11-year-old children support the findings of the literature. Intellectual growth as measured by memory span increases with age (Case, 1985; Case, Kurland & Goldberg, 1982; Dempster, 1981).

The question is not whether memory span increases with age but exactly what processing changes occur that enable the memory span to increase. Beyond the processing changes underlying memory span increase are the neurological factors that may play a role.

Neurophysiological findings of this study agree with those of Gamstorp (1963), Martinez et al. (1978), Wagner and Buchthal (1972), with respect to conduction velocity changes in the median nerve between 3 and 11 years of age. Mean conduction velocity of 3-year-olds was 48.2 m/s, for 11-year-olds was 60.1 m/s, Central conduction times, N14-N20, and N14 - P22 also decreased significantly with increase in age.

One measure of intellectual development that takes place with age is the increase in memory span or short term storage space (STSS) (Case, 1985; Case et al., 1982; Dempster, 1981). This present study used two experimental tests to measure short term storage space in 3-and 11-year-old children. Neurophysiological development was measured electrophysiologically using somatosensory evoked potentials with median nerve stimulation. This allowed measurement of conduction speeds. Conduction speeds increase with age and reflect changes in the nervous system that include synaptic formation, biochemical maturation of neurons, myelination, and dendritic and axonal elaboration (Holmes, 1986).

Case's (1985) model of intellectual development hypothesized myelination to be the neurological factor that contributed to the increase of STSS. Evoked potential tests are used to diagnose neurological diseases such as multiple sclerosis in which there is known myelin degeneration. More information is available on myelin and its development than on accompanying neurological changes such as synaptic formation, axonal and dendritic growth. However, with the increasing knowledge of the remarkable physiological changes that occur in the maturing nervous system, it is not possible to assign sole responsibility for STSS increase to any one of the maturational changes including the process of myelination.

Educational implications resulting from this study indicate that from a developmental viewpoint cognitive processes can be limited by neurological maturation. Educators tend to emphasize practice and performance in learning. In addition they need to be aware of the limitations imposed on cognitive processes by neurological maturation and design appropriate levels of material to be presented to the child.

Using somatosensory evoked potentials, no neurophysiological differences appeared between children with good memory scores and age-matched peers with poor memory scores. No neurological differences occurred within the somatosensory pathway although

there were significant differences in the memory scores.

This study has shown that with an increase in age there is a significant correlation between cognitive development as measured by memory span and physiological development as measured by central conduction time.

With available technology, we can now analyze electrical activity in the brain and correlate these activity changes with cognitive processes. This interfacing of neurological maturation with cognitive functioning will lead us to a comprehensive view of the child as an integrated whole.

Recommendations For Further Research

Continued research might include a study of subjects who have multiple sclerosis with known myelin degeneration and then proceed to correlate their memory scores with conduction times. This research would be able to focus specifically on the role of myelin and its relationship to STSS.

The present study was intended to be a pilot and requires replication using an increased number of subjects that include ages between 3 and 11 years of age. Using the N14 component as a base, latency times for components later than N20 and P22 could

be tested to see if interpeak intervals correspond with STSS levels.

This study showed that children labeled learning disabled who had poor memory scores had similar central conduction times to age-matched peers. Obrzut et al. (1987) reviewed recent studies that indicated significant differences in brain stem evoked responses between learning disabled children and age-matched peers. A further study could identify learning disabled children by psychoeducational testing, then subject them to a brain stem evoked potential and a somatosensory evoked potential and compare the results with age-matched peers.

Many developmental theories have contributed to the structure of assessment instruments that are available to measure intellectual development. Using these assessment tests as indicators as well as empirical studies, it is generally agreed that children's intellectual functioning becomes increasingly complex with increasing age. General stages are reached at approximately the same time by all normal children suggesting that neurological maturation plays some role in cognitive growth. Neurophysiological factors have been recognized for many years as contributing to the child's intellectual development but until recently they have remained in the realm of theory and

speculation. With improved instrumentation and electrophysiological technology, it is now possible to measure neurological changes that occur with learning and correlate these changes with cognitive developments that take place.

Bibliography

- Allison, T., & Hume, A. (1981). A comparative analysis of short latency somatosensory evoked potentials in man, monkey, cat and rat. Experimental Neurology, 72, 592-611.
- Baddeley, A. (1986). Working memory. Oxford: Clarendon Press.
- Baldwin, J. (1894). The development of the child and of the race. New York: MacMillan. (Reprinted by Augustus M. Kelley, 1968).
- Bruner, J.S. (1964). The course of cognitive growth. American Psychologist, 19, 1-15.
- Case, R. (1985). Intellectual development - Birth to adulthood. Orlando: Academic Press.
- Case, R., Kurland, M., & Goldberg, J. (1982). Operational efficiency and the growth of short term memory. Journal of Experimental Child Psychology, 33, 386-404.
- Chiappa, H. (1983). Evoked potentials in clinical medicine. New York: Raven Press.
- Chusid, J.G. (1982). Correlative neuroanatomy and functional neurology. Los Altos: Lange Medical Publications.
- Cracco, J.B., & Cracco, R.Q. (1982). Spinal somatosensory evoked potential: maturational and clinical studies. Ann. N.Y. Acad. Sci., 338, 526-537.
- Cracco, J.B., Cracco, R.Q., & Graziani, L.J. (1975). The spinal cord evoked response in infants and children. Neurology, 25, 31-36.
- Cracco, J.B., Cracco, R.Q., & Stovelove, R. (1979). Spinal evoked potential in man: a maturational study. Electroencephalography and Clinical Neurophysiology, 46, 58-64.

- Dekaban, A. (1970). Neurology of early childhood. Baltimore, MD: Williams & Wilkins.
- Dempster, F.N. (1981). Memory span: sources of individual and developmental differences. Psychological Bulletin, 89, 63-100.
- Desmedt, J.E., Brunko, E., & Debecker, J. (1976). Maturation of somatosensory evoked potentials in normal infants and children. Electroencephalography and Clinical Neurophysiology, 40, 43-58.
- Desmedt, J., Cheron, G. (1981). Non-cephalic reference recording of early somatosensory potentials to finger stimulation in adult or aging normal man: differentiation of widespread N18 and contralateral N20 from the prerolandic P22 and N30 components. Electroencephalography and Clinical Neurophysiology, 52, 553-570.
- Dobbing, J., & Sands, J. (1973). Quantitative growth and development of human brain. Archives of Diseases of Childhood, 48, 757-767.
- Dorfman, L.J., & Bosley, T.M. (1979). Age related changes in peripheral and central nerve conduction in man. Neurology, 29, 38-44.
- Epstein, C.M. & Andriola, M.R. (1983). Introduction to EEG and evoked potentials. Pa: Lippincott.
- Gamstorp, I. (1963). Normal conduction velocity of ulnar, median, and peroneal nerves in infancy, childhood and adolescence. Acta Paediatrica Suppl., 146, 68-76.
- Garoutte, B. (1983) Survey of functional neuroanatomy. Greenbrae, Ca: Jones Medical Pub.
- Gilmore, R.L., Bass, N.H., Wright, E.A., Greathouse, D., Stanback, K., Norwall, E. (1985). Developmental assessment of spinal cord and cortical evoked potentials after tibial nerve stimulation: effects of age and stature on normative data during childhood. Electroencephalography and Clinical Neurophysiology, 62, 241-251.

- Harmony, T. (1984). Neurometric assessment of brain dysfunction in neurological patients. Functional Neuroscience (Vol. 3). Hillsdale, NJ: Earlbaum Associates.
- Holmes, G.L. (1986). Morphological and physiological maturation of the brain in the neonate and young child. Journal of Clinical Neurology, 3, 209-238.
- Howard, L. & Polich, J. (1985). P300 latency and memory span development. Developmental Psychology, 21,
- Hume, A.L., Cant, B.R., Shaw, N.A., Cowan, J.C. (1982). Central somatosensory conduction time from 10 to 79 years. Electroencephalography and Clinical Neurophysiology, 54, 49-54.
- Huttenlocher, J., & Burke, D. (1976). Why does memory span increase with age? Cognitive Psychology, 8, 1-31.
- Humphreys, M.S., Lynch, M.J., Revelle, W., Hall, J.W. (1983). Individual differences in short-term memory. Individual differences in cognition. pp. 35-61. Academic Press.
- John, E.R. (1981). Neurometric evaluation of brain dysfunction related to learning disabilities. Acta Neurologica Scandinavica, 63, (Supp. 89), 87-100.
- Joyce, B. & Weil, M. (1980). Models of teaching (2nd ed.). Englewood Cliffs, NJ: Prentice-Hall.
- Kandel, E.R. (1979). Small systems of neurons. Scientific American, 241, 66-68.
- Kaufman, A.S. (1979). Intelligence Testing with WISC-R. New York: Wiley.
- Lastismosa, A.C., Bass, N.H., Stanback, K., Norwell, E. (1982). Lumbar spinal cord and early cortical evoked potentials after tibial nerve stimulations: effects of stature on normative data. Electroencephalography and Clinical Neurophysiology, 54, 499-507.

- Lee, K.H., Chung, K., Chung, J.M., Coggeshall, R.E. (1986). Correlation of cell body size, axon size and signal conduction velocity for individually labeled dorsal root ganglion cells in the cat. Journal of Comparative Neurology, 243, 335-346.
- Licht, S. (1980). History of electromyography. In E.W. Johnson (Ed.), Practical electromyography (Chapt. 17). Baltimore, MD: Williams & Wilkins Co.
- Martinez, A., Ferrer, M., Conde, M., Bernacer, M. (1978). Motor conduction velocity and H-reflex in infancy and childhood. Electromyography and Clinical Neurophysiology, 18, 11-27.
- Mauguiere, F. & Courjon, J. (1981). The origins of short latency somatosensory evoked potentials in humans. Ann. of Neurological, 9, 607-610.
- Nakashini, T., Tamaki, N., Mizusawa, H., Akatsuka, T., Kinoshita, T. (1986). An experimental study for analyzing nerve conduction velocity. Electroencephalography and Clinical Neurophysiology, 5, 484-487.
- Nicolet Biomedical Instruments. (1981). CA-1,000 evoked potential recording techniques. Madison, Wis: Author.
- Obrzut, J.E., Morris, G.L., Wilson, S.L., Lord, J.M., Caraveo, L.E. (1987). Brainstem evoked response in the assessment of learning disabilities. International Journal of Neuroscience, 32, 811-823.
- Peele, T.L. (1977). The neuromatic basis for clinical neurology. New York: McGraw-Hill.
- Precht, H.F.R. (1981). The study of neural development as a perspective of clinical problems. In K.J. Connolly and J.F.R. Precht (Eds.), Maturation and development: Biological and psychological perspectives (pp. 198-215). London: Heinemann.
- Rorke, L., & Riggs, H. (1969). Myelination of the brain in the newborn. Philadelphia: Lippincott.

- Rosenzweig, M.R. & Bennett, E.L. (Eds.). (1976). Neural mechanisms of learning and memory. Cambridge, MA: MIT Press.
- Sances, A., Larson, S., Crusick, J.F. (1978). Early somatosensory evoked potentials. Electroencephalography and Clinical Neurophysiology, 45, 505-514.
- Seaman, J.A., & De Pauw, K.P. (1982). The new adapted physical education: a developmental approach. Palo Alto: Mayfield.
- Schulte, F. (1974). Nerve conduction velocity. In Berenberg, Canniaris and Mosse (Eds.), Pre and post natal development of the human brain. New York: S. Karger.
- Wagner, A.L., & Buchthal, F. (1972). Motor and sensory conduction in infancy and childhood: Reappraisal. Developmental Medicine and Child Neurology, 14, 189-210.
- Williams, H.G. (1983). Perceptual and motor development. Englewood Cliffs, NJ: Prentice-Hall.
- Yakovlev, P.I., & Lecours, A.R. (1967). The myelogenic cycles of regional maturation of the brain. In A. Minkowski (Ed.), Regional development of the brain in early life. (pp. 3-71). London: Blackwell Scientific Publications.

APPENDIX I

DEFINITIONS

DEFINITIONS

This study contains several terms requiring definitions. Case's analytic units are defined because of the unusual terminology he has used. Other definitions refer to medical terms that are generally unfamiliar in the educational field.

Executive processing space - maximum numbers of independent schemes that a subject can keep in a state of full activation simultaneously while working toward a goal about which some executive decision must be made (Case, 1985, p. 289).

Operating space (OS) that proportion of a subject's total executive processing space that is currently being devoted to the activation of new schemes (Case, 1985, p.289).

Short term storage space (STSS) - that proportion of a subject's total executive processing space that is currently being devoted to maintenance and/or retrieval of recently activated schemes (Case, 1985, p.289).

Myelin - the lipoprotein covering found on many nerve fibres. It acts as an insulator of the nerve fibre and is responsible for faster conduction of nerve impulses. (Williams, 1983, p. 67).

Somatosensory - sensory activity having its origin elsewhere than in the special sense organs and conveying information about the state of the body proper and its immediate environment (Websters Medical Desk Dictionary).

Somatosensory evoked potential - changes in electrical potential generated by activity in neurons in somatosensory pathways, including peripheral nerve, spinal cord, brain stem and cortex.

Peripheral nervous system - that part of the central nervous system that lies outside the cranium and vertebral column.

Central nervous system - includes the brain and spinal cord.

Central conduction time - In this study CCT was the time required for neural activity to travel from the brain stem (N14) to the primary somatosensory cortex (N20). CCT is measured in milliseconds (ms).

Peripheral conduction velocity - a calculation in metres per second (m/s) made by dividing the arm length (wrist to collarbone) by the time it takes nerve activity to travel from wrist to collarbone.

Surface electrodes - metal electrodes placed on the skin surface.

Inion - occipital protuberance (Webster's Medical Desk Dictionary).

Nasion - mid-point of nasal frontal suture (Webster's Medical Desk Dictionary).

Zygomatic Arch - the zygomatic process, a conspicuous bar of bone of the face to form the zygomatic arch. (Human Anatomy and Physiology Pg. 177).

APPENDIX 2

SCORING SHEET FOR SHORT-TERM STORAGE ITEMS (FINE MOTOR)

FINE MOTOR SHORT-TERM STORAGE ITEMS

- Tasks - circle thumb and forefinger
 - a V with fingers
 - point with finger
 - a fist
 - two fists
 - five finger stretched
 - two hands, fingers crossed

<u>Level</u>	<u>Trial 1</u>	<u>Trial 2</u>	<u>Trial 3</u>	Scores
				<u>Lib.</u> <u>Cons.</u>
1	circle point	fist 5 fingers	a "V" fingers x'd	
2	2 fists 5 fingers circle	point a "V" fist	5 fingers fingers x'd point	
3	a "V" circle fist 5 fingers	2 fists fingers x'd point fist	circle a "V" fingers x'd point	
4	5 fingers circle a "V" 2 fists point	fingers x'd 1 fist point circle 5 fingers	point 2 fists circle fingers x'd a "V"	

APPENDIX 3

SCORING SHEET FOR SHORT-TERM STORAGE
ITEMS (GROSS MOTOR)

GROSS MOTOR SHORT-TERM STORAGE ITEMS

Tasks - throw
 - clap
 - jump
 - wig-wag
 - wave
 - kick
 - tip-toe

				Scores
<u>Level</u>	<u>Trial 1</u>	<u>Trial 2</u>	<u>Trial 3</u>	<u>Lib. Cons.</u>
1	clap jump	tip-toe wave	kick wig-wag	
2	wave tip-toe kick	jump clap throw	tip-toe wig-wag wave	
3	throw jump wig-wag kick	clap tip-toe wave throw	wig-wag clap kick jump	
4	jump throw wig-wag tip-toe wave	wig-wag kick clap throw jump	wave throw kick clap tip-toe	
5	wig-wag kick wave jump throw tip-toe	kick throw clap tip-toe throw wave	throw tip-toe wig-wag wave kick jump	
6	clap jump wig-wag wave kick tip-toe throw	wave clap kick jump tip-toe throw wig-wag	tip-toe wave wig-wag throw clap jump kick	

APPENDIX 4

LETTER OF CONSENT TO THE PARENTS OF SUBJECTS

LETTER OF INTENT AND CONSENT TO THE PARENTS OF SUBJECTS

This is a request for permission to have your son/daughter participate in a study which seeks to discover whether the speed with which a message is sent along a nerve is related to the number of items that a child can remember. This is a new hypothesis in educational thought and could have a marked influence if a relationship were to be found.

The study is being carried out by Marilyn Butt in partial completion of a Master's Degree in Education at Brock University. The faculty advisor is Dr. J. Wagner.

There will be three tasks for your child. One is called a somatosensory evoked potential which will be administered by trained experienced technicians in the electroencephalography department at the University of Alberta Hospital. This test tells us how quickly a sensation is transferred along the nerves. In this study, we are measuring the time it takes for a sensation to travel along the median nerve in the forearm until it is recorded at the scalp. Electrodes will be pasted to the skin surface at the wrist, collarbone, back of the neck, and on the scalp. A mild electrical stimulus will be given at the wrist. The resulting feeling, as I experienced it, is that of a ruler being repeatedly tapped gently along the thumb. This sensation will last for about one minute. The data collected will contribute to the medical professions' knowledge of conduction times in specific age groups.

The other two tasks are for memory and are similar in nature. We will do them at home or at school (wherever the child is comfortable). These will consist of items such as waving, clapping hands, etc. something like "Simon Says" games and the children have to remember them in sequence. This takes about half an hour.

For the purposes of this study, your child should be 3 years or 11 years old and have no known mental, physical or emotional disorder.

This study will contribute to our knowledge of the underlying principles of learning. All information will remain confidential.

Thank you for your cooperation.

Marilyn Butt
464-4370

I am aware of the tasks and consent to have my child participate in a study carried out by Marilyn Butt under the supervision of Dr. J. Wagner of Brock University.

APPENDIX 5

DATA

GROUP I

11-YEAR-OLDS MEMORY SCORE 12+

Gender	Age (yrs.)	Height (cm)	Digit Span (Scaled Score)	Fine Motor Memory Level	Gross Motor Memory Level	CCT N14--N20 (msec)	CCT N14--P22 (msec)	Peripheral CV (msec)	Ipat Scores			
						R	L	R	L			
M	11.4	144	12	2	3	5.5	5.4	59	60	97		
M	11.2	152	12	3	2	5.7	5.7	8.9	9.1	60.4		
M	11.3	141	12	2	3	5.9	5.6	9.4	8.5	57.4		
M	11.8	170	12	3	3	6.3	6.2	8.4	8.8	56.5		
M	11.9	149	17	3	5	5.9	5.6	8.2	8.1	55.0		
M	11.9	159	16	4	3	5.5	5.9	8.0	8.4	54.5		
M	11.9	143	13	3	2	5.8	6.0	8.3	7.8	65.1		
F	11.9	158	12	4	4	5.4	5.4	9.4	8.9	62.9		
F	11.6	148	15	2	2	5.5	5.9	9.0	9.0	57.0		
F	11.5	148	12	3	3	5.0	5.5	8.8	9.3	65.1		
F	11.1	141	13	2	3	6.1	5.9	11.9	11.9	61.4		
F	11.4	159	12	4	4	5.7	-	8.3	-	64.2		
F	11.2	146	13	4	5	5.7	5.7	9.0	8.3	61.3		
-												
X	11.5	150.6		13.23	3	3.3	5.69	5.7	8.9	8.9	60.0	60.2
SD	.30	8.646		1.69	.816	.96	.330	.316	1.03	1.08	3.58	
SE	.027	2.498		.488	.235	.277	.095	.095	.311	.344	1.03	
-												
X							R + L		R + L		R + L	
SD							5.70		8.90		60.1	
SE							.289		1.03		3.58	
N							.059		.220		.401	
							25		23		26	

GROUP II

11-YEAR-OLD MEMORY SCORE 7 AND BELOW

Gender	Age (yrs.)	Height (cm)	Digit Span Scores (Scaled)	Fine Motor Memory Level	Gross Motor Memory Level	CCT R	N14-N20 L (msec)	CCT R	N14-P22 L (msec)	Peripheral CV (msec)	Ipat Scores
M	11.2	145	7	1	2	6.7	6.5	7.8	8.2	55.8	55.8
M	11.5	146	5	2	2	6.1	5.3	9.8	8.8	65.8	67.0
M	11	144	7	1	2	5.5	5.6	7.9	8.0	61.0	63.6
M	11	144	7	2	3	5.6	5.0	7.8	7.9	60.6	64.2
M	11.4	143	7	2	2	5.8	5.9	8.5	8.6	58.2	57.6
M	11	145	6	2	3	5.9	6.6	-	-	58.5	56.2
M	11	140	4	1	1	6.1	6.3	9.1	9.0	50.5	52.5
M	11	143	3	2	2	6.8	6.6	-	-	53.7	55.9
M	11.3	139	3	2	1	5.4	4.4	8.3	8.2	62.9	64.1
M	11.9	148	7	2	3	5.3	6.9	-	-	60.6	62.3
M	11.3	143	6	1	2	5.0	5.6	9.2	7.9	61.1	60.4
F	11	140	7	1	1	5.5	5.6	8.6	8.8	60.0	61.9
F	11	148	7	3	2	5.5	5.5	7.7	8.3	59.3	60.2
F	11.3	146	5	2	2	5.8	5.8	-	-	62.3	63.5
F	11.3	150	7	1	2	5.5	-	-	-	59.7	59.7
-											
X	11.2	144	5.86	1.6	2.0	5.83	5.9	8.4	8.37	59.3	60.3
SD	.258	3.12	1.5	6.1	.65	.449	.579	.71	.402	3.75	4.03
SE	.069	.836	.402	.16	.175	.120	.16	.237	.134	1.00	1.08
N	15										
-											
X						R + L		R + L		R + L	
						5.86		8.42		59.83	
SD						.507		.565		3.86	
SE						.095		.188		.717	
N						29		20		30	

GROUP III

3-YEAR-OLDS

Gender	Age (yrs)	Height (cm)	Fine Motor Memory Level	Gross Motor Memory Level	CCT N14-N20 (msec)	CCT N14-P22 (msec)	Peripheral CV (msec)				
					R	L	R	L			
M	3	94	1	1	6.0	6.0	11.0	11.0	46.3	46.3	
M	3	94	2	2	6.6	6.7	12.0	11.8	45.8	45.8	
M	3.7	99	1	1	6.3	6.5	9.7	10.0	48.5	49.2	
M	3.5	103	1	1	7.1	6.5	11.3	11.4	52.3	45.3	
M	3.8	96	1	1	6.2	7.0	10.7	11.3	45.8	47.1	
M	3.5	106	1	2	6.7	6.7	10.5	10.6	44.0	46.6	
F	3.7	102	2	2	6.9	6.0	9.8	8.3	45.8	43.2	
F	3.5	95	1	2	6.9	6.5	11.0	9.7	53.0	50.0	
F	3.8	99	1	2	6.1	6.8	9.6	10.1	48.5	51.5	
F	3.5	95	1	1	7.1	6.3	11.0	9.7	50.7	50.7	
F	3.5	98	1	1	7.3	6.7	9.9	9.8	50.0	50.0	
F	3.5	98	1	2	6.6	7.1	9.1	8.8	49.2	48.5	
-											
X	3.5	97.8		1.16	1.5	6.73	6.65	10.75	10.53	48.8	47.9
SD	.27	3.99		.389	.522	.558	.436	1.419	1.422	2.78	2.46
SE	.082	1.21		.117	.157	.168	.131	.427	.429	.838	.742
N12											
-											
X						R + L		R + L		R + L	
SD						6.7		10.3		48.2	
SE						.355		.947		2.57	
						.074		.19		.536	